CLIMATE CHANGE: EVIDENCE AND FUTURE PROJECTIONS

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Good morning, Mr. Chairman and members of the Committee. My name is Ralph Cicerone, and I am President of the National Academy of Sciences. Prior to this position, I served as Chancellor of the University of California at Irvine, where I also held the Daniel G. Aldrich Chair in Earth System Science and was Professor of Chemistry. In addition, in 2001 I chaired the National Research Council committee that wrote the report, *Climate Change Science: An Analysis of Some Key Questions*, at the request of the White House.

This afternoon I will summarize the state of scientific understanding on climate change, based on the findings and recommendations in National Academy of Sciences and National Research Council reports and in recent refereed scientific publications. Although not part of the government, the National Academy of Sciences was chartered in 1863 to advise the government on matters of science and technology. Our reports, often written with the National Academy of Engineering and the Institute of Medicine, are the products of a study process that brings together leading scientists, engineers, public health officials, and other experts to provide consensus, peer-reviewed advice to the nation on scientific and technical questions.

The greenhouse effect is a natural phenomenon. Without greenhouse gases, the surface of the Earth would be about 60^{o}F (33^{o}C) colder than it is today. Now, humans are amplifying the greenhouse effect by increasing the concentrations of many greenhouse gases (carbon dioxide, methane, nitrous oxide, synthetic chlorofluorocarbons and other fluorocarbons, and tropospheric ozone) in the atmosphere. The extra energy trapped near

Earth's surface by the human-amplified greenhouse effect is presently about 2.5 Watts per square meter, which is about 100 times larger than all human energy usage.

There is no doubt that the Earth is warming. Weather-station records and ship-based observations show that global average surface air temperature has increased by about 1.2^{o}F (0.7^{o}C) since the beginning of the 20th century, more than half of it since 1975. Scientists have also measured upward temperature trends in the lower atmosphere and in the upper oceans, and this continuing warming has been accompanied by worldwide changes in many other indicators, such as shifts in ecosystems and decreases in Arctic sea ice thickness and extent.

Last week you heard testimony from Dr. Gerald North, chair of the National Research Council committee that examined surface temperature reconstructions for the last 2,000 years derived from tree rings, boreholes, ice cores, glacier length records, and other types of proxy evidence. The committee concluded that the Earth was warmer during the last few decades of the 20th century than at any other time during at least the last 400 years, and potentially the last several thousand years. These temperature reconstructions provide a useful context for evaluating late 20th century warming. However, they are not the primary evidence for the widely accepted view that global warming is occurring, that human beings are responsible, at least in part, for this warming, and that the Earth's climate will continue to change during the next century.

Many additional lines of evidence demonstrate that climate is changing:

- Measurements show large increases in carbon dioxide and other greenhouse gases (methane and nitrous oxide, for example) beginning in the middle of the 19th century. These increases in greenhouse gases are due to human activities such as burning fossil fuel for energy, industrial processes, and transportation. The concentration of carbon dioxide in the atmosphere is now at its highest level in 650,000 years and continues to rise.

- We understand how carbon dioxide and other greenhouse gases affect global temperature. Rigorous radiative transfer calculations of the temperature changes associated with increasing greenhouse gas concentrations, together with reasonable assumptions about climate feedbacks, provide a physically based theoretical explanation for the observed warming.

- State-of-the-art mathematical climate models are able to reproduce the warming of the past century only if human-caused greenhouse gases are included.

- Analysis of high-quality, precise measurements of the Sun's total brightness over the past 25 years shows that there has been little if any change in the long-term average of solar output over this time period. Thus, changes in the Sun can not explain the warming observed over the past 25 years.

- The oceans have warmed in recent decades and the stratosphere has cooled. Extratropical land masses in the Northern Hemisphere have warmed even more than the oceans. These large-scale changes are consistent with the predicted spatial and temporal pattern of greenhouse surface warming.

- Ice covered regions of the Earth have experienced significant melting. For example, the annual average sea-ice extent in the Artic has decreased by about 8%, or nearly one million square kilometers, over the past 30 years. Measurements from Earth-orbiting satellites (from synthetic aperture radars and from Earth's gravity sensors) over the last few years have shown that both the Greenland and West Antarctic Ice Sheets are losing ice.
- Several publications in 2005 and 2006 show that hurricane intensities have increased in some parts of the world, in lock step with oceanic warming.

While we are quite certain that the Earth's surface has warmed rapidly during the last 30 years and that it is warmer now than at any other time during at least the last 400 years, projecting what will happen to important climate variables in the future is more difficult. As stated in the 2001 NRC report, "climate change simulations… yield a globally averaged surface temperature increase by the end of the century of 2.5 to 10.4^{o}F (1.4 to 5.8^{o}C) relative to 1990." Since 2001, we have continued to make advances in our knowledge of the climate system and in our ability to model it mathematically. Yet, pinpointing the magnitude of future climate changes is hindered both by remaining gaps in our ability to simulate scientific phenomena, and by the fact that it is difficult to predict society's future actions, particularly in the areas of population growth, energy consumption, and energy technologies. In general, temperature is easier to predict than changes such as rainfall, storm patterns, and ecosystems.

While future climate change and its impacts are inherently uncertain, they are far from unknown. A broad-brush picture of how global warming may affect certain regions of the world is starting to emerge from climate modeling efforts. Models generally project more warming in continental regions than over the oceans and in polar regions than near the equator. Precipitation is expected to increase in the tropics, decrease in the subtropics, and increase in the midlatitudes. Rainfall is also expected to increase in the monsoon regimes in South Asia, West Africa, and South America; these changes may create the potential for stronger El Niño events. Some models indicate that midlatitude continents will likely be drier during the summer in a warmer climate, leading to an increased chance for summer drought conditions.

Even if no further increases in the atmospheric concentrations of greenhouse gases occur, we are very likely to experience additional warming of 0.7°F (0.4°C). In colder climates, such warming could bring less severe winters and longer growing seasons (if soil moisture is adequate). Several studies have projected that summertime ice in the Arctic could disappear by A.D. 2100. The combined effects of ice melting and sea water expansion from ocean warming will likely cause the global average sea level to rise by between 0.1 and 0.9 meters between 1990 and 2100. Those in coastal communities, many in developing nations, will experience increased flooding due to sea level rise and are likely to experience more severe storms and surges. Increasing acidification of the surface ocean (due to added carbon dioxide from the atmosphere) will harm marine organisms such as corals and some plankton species.

In summary, there are multiple lines of evidence supporting the reality of and human roles in global climate change. The task of mitigating and preparing for the impacts of climate change will require worldwide collaborative inputs from a wide range of experts, including natural scientists, engineers, social scientists, medical scientists, those in government at all levels, business leaders and economists. For example, researchers and resource managers have only begun to address how climate change will impact future demands for electricity and water. Society faces increasing pressure to decide how best to respond to climate change and associated global changes, and applied research in direct support of decision making is needed.

Appendixes

- Joint science academies' statement: Global response to climate change
- *Understanding and Responding to Climate Change: Highlights of National Academies Reports* (2005)